Dr. Nova's IB Physics Cram: Digital Technology

(WARNING: not a substitute for regular review!)

Transfer of information electronically between broadcaster and receiver can be accomplished by two types of signals.

1. Analogue signals – are continuous electrical signals that vary in amplitude over time. The variations in the analogue signal follow the variations of the original physical quantity (hence they are "analogous"). An example would be a telephone signal – the analogue signal varies with the intensity and frequency of the speaker's voice. This signal is translated back to sound in the receiver.
2. Digital signals – are non-continuous pulses (digits) of discrete amplitude or value (i.e. a binary digital signal is either a 0 or a 1). Sequences of digits code information that is being transmitted.

Binary Number System

One "digit" of information is called a bit. A sequence of 8 digits is called a byte.
In binary, a bit can be either a 0 or a 1 (OFF or ON, TRUE or FALSE). Binary is a base 2 system of information encoding. 1, 2, 4, 8, 16, 32, 64, 128 etc.
The Least Significant Bit (the rightmost bit) represents the smallest power of 2 → 2^0
The Most Significant Bit (the leftmost bit) represents the largest power of 2. In a byte of information, this would be 2^8.
Consider the decimal (base 10) value 13.

$$13 = 8 + 4 + 0 + 1 = 2^3 + 2^2 + 0 + 2^0 = 00001101 \text{ in binary}$$

Similarly, the binary signal 00010101 represents

$$2^0 + 2^2 + 2^4 = 1 + 4 + 16 = 21 \text{ in decimal}$$

Examples of digital and analogue information coding for storage and transfer

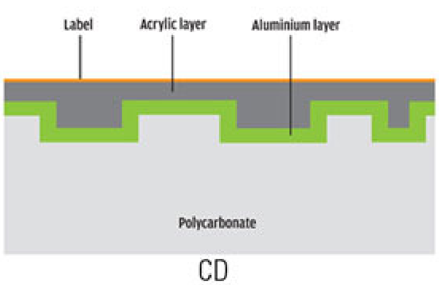
Analogue	Digital
Photocopying – optical and electrostatic device creates hard copy (not 100%) of original.	Floppy Disks – uses two magnetic variations to store data.
Microfiche – Optical process creates micro version of original document	Microchips – bits of information are stored utilizing two possible variations of electrical signal (ON or OFF) within the chip.
LP's (records) – sound signal is embedded physically as variations on vinyl surface	CD's & DVD's - variations representing audio and video are stored as "bumps" on disc surface that are read optically.
Cassette Tapes – sound signal is stored by variations of magnetized portions on the tape. Reusable but quality decreases.	Hard Disks – similar to floppy disk Flash memory is similar to a microchip.

Information storage and recovery on a CD

A typical store bought music CD has a layered structured similar to that shown below.

Below the label a very thin aluminum coated membrane layer contains the data. The bulk of the disk is a 1.2 mm thick polycarbonate layer.

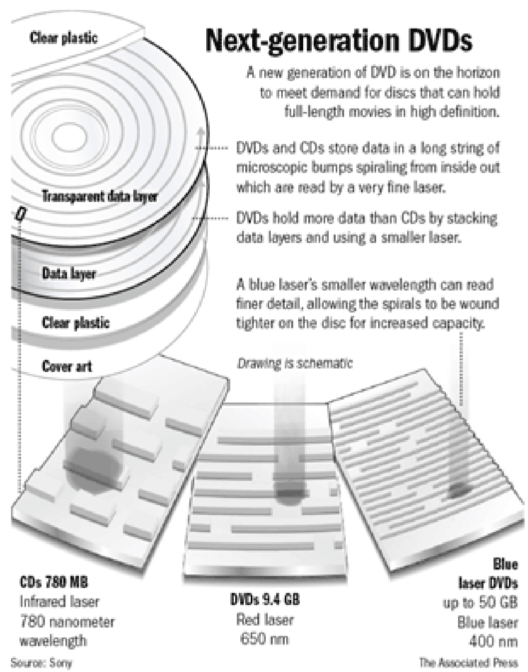
Most disk damage is done by scratching the label side!!

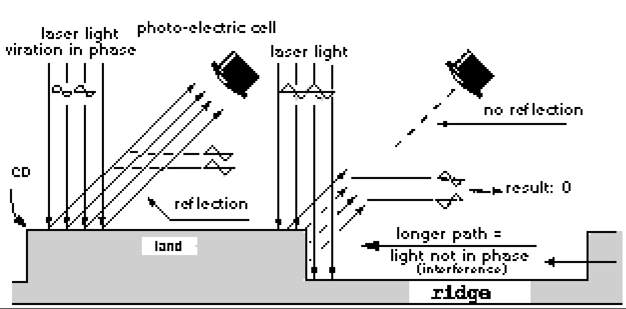


Problems involving data storage on CD's

A few key concepts may be required to interpret a variety of possible problems:

- The depth of pits = ¼ λ of the laser light being used
- A "track" on a CD is the stream of digitally encoded information that is laid out in a spiral pattern on the disk.
- It follows that a track length will depend on the number spirals and the radius (which will get smaller as the disk center is approached)
- CD's use 16 bit sampling. Each sample uses 16 bits and a standard CD samples at 44.1 kHz. That means 1 second of recorded audio uses $(44.1 \times 10^3) \times 16$ bits. This is for just one channel. If the recording is in stereo then the number of bits each second doubles.
- The sample problems on page 115 of Kirk are a good illustration of these concepts.





- Information is stored on a CD in the aluminum layer as a series of "bumps". This creates raised surfaces (land) and depressions (pits).
- A laser shines on the disk surface. When the laser strikes "land" a photoelectric cell picks up a strong signal (rays interfere constructively) and a zero is recorded.
- In the pits, the same thing happens.
- A 1is recorded in the transition between land and pit. The pit depth is ¼ λ so destructive interference occurs; only a weak signal is detected.
- Disk rotation speed varies depending on laser reader distance from center. As laser moves outward, rotation is slowed.

Advantages of digital information storage

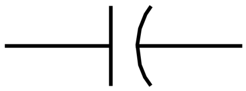
- Digital information is less liable to damage or corruption so quality of output is preserved
- Optical devices do not wear or damage media, quality does not decrease with copying or playing
- Retrieval of data is faster
- Data storage media is more portable
- Data can be manipulated (copied, mixed, deleted) easily

14.2 CCD's

Capacitance – a capacitor is a device that stores charge (q). The capacitance of a capacitor relates the amount of charge that can be stored for a given P.D. (V).

Mathematically: $q = C \times V$ unit is the farad (F).

Capacitance is related to the geometry of the device. Knowing capacitance allows the stored charge to be calculated for a given P.D. The symbol for a capacitor (not in Data booklet) is



CCD (charge coupled device) – diagram right (Wikipedia)

A CCD is a silicon (semiconductor) chip that is divided into a number of small areas called pixels – the more pixels, the greater the resolution

- Each pixel can function as a capacitor and store charge

How a CCD functions – the basic steps (4 of them)

- Incident light stimulates photoelectric effect in pixels
- charge builds up in pixels proportional to light intensity
- charge is collected by coupling into packets that are transferred across the pixel array to an electrode
- each packet measured and output voltage (analogue) and pixel position are converted to a digital signal

In more detail

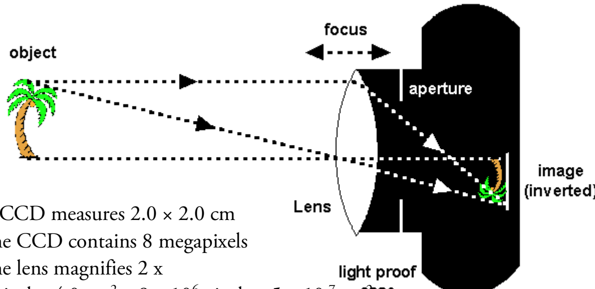
1. Incident light shines on the CCD
2. Each pixel emits electrons dependent on the intensity (number of photons per unit time) of the incident light. This is an application of the photoelectric effect.
3. Charge builds up on pixels dependent on light intensity. The pixels therefore act as capacitors.
4. Charge ∝ number of photons ∝ intensity
5. A control circuit tells each pixel to transfer its charge to its neighbor. This is what is inferred by "charge coupling"
6. The last pixel in the array dumps its charge into an amplifier.
7. The amplifier converts the charge into a voltage.
8. The sequence of voltages in the array are sampled, digitized and stored in some form of memory.

Quantum Efficiency

- Defined as the ratio of photoelectrons to incident photons
- A perfect CCD would emit one electron for each incident photon
- Efficiency depends on the design/materials of CCD and (obviously) the frequency of the incident light.

Magnification and Resolution

- Defined as the ratio of a dimension on a CCD image to the dimension on the actual object
- Magnification is related to the resolution of the image.
- In a digital camera, the lens magnifies and focuses the object on the CCD. The image on the CCD is recorded. How well the image is resolved depends on the pixel density.
- If the distance between two points on the object is less than the distance between two pixels on the CCD, then that detail is not resolved.
- This implies that the more pixels per unit area on the CCD, the greater the resolution



For example

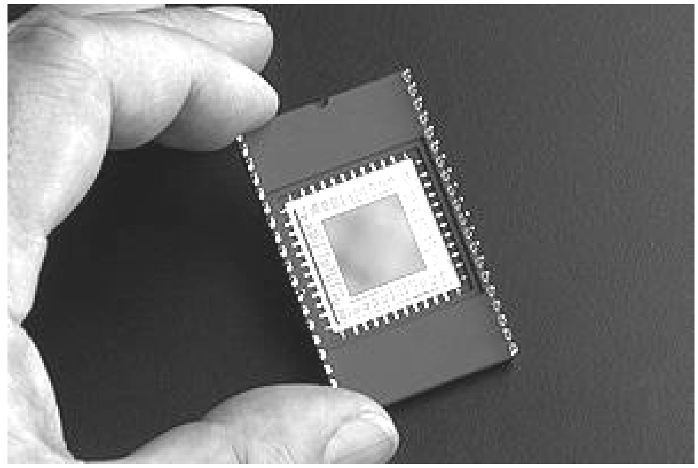
- a CCD measures 2.0 × 2.0 cm
- the CCD contains 8 megapixels
- the lens magnifies 2 x

Area of each pixel = $4.0\ cm^2 \div 8 \times 10^6$ pixels = $5 \times 10^{-7}\ cm^2$

Length of one pixel = separation between two pixels = 7.07×10^{-4} cm

On the object the limits of resolution would be twice that (due to magnification)

∴ any dimension on the object > 0.001 cm is resolved



Practical Uses of CCD's

- Pretty much anywhere that images need to be captured including
  - Digital cameras (still and video)
  - In conjunction with microscopes and telescopes
  - Medical imaging – note that CCD's can be constructed to respond to x-ray photons for example.
  - Scanners

Advantages

- In some cases, greater resolution and higher quality images (expensive cameras). Digital video is better because magnetic tape is no longer used (see digital vs analogue on previous page)
- Costs lower – no more film required
- Quantum efficiency higher than film – means low light imaging is easier and more detailed with CCD's
- Digital images can be stored, viewed, and enhanced very quickly and easily with readily available software.

What makes an optimum CCD device?

- High quantum efficiency
- High lens quality for greater magnification – gives greater resolution i.e. a small object is magnified over a greater area on the CCD.
- More pixels – related to resolution above. A greater resolution can be achieved without magnification if the pixel density is increased.